Final Report

On

Phase II of Long-term Properties of Corrugated HDPE Pipes

To

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By

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February 7th, 2012

1. INTRODUCTION

The current material design properties of corrugated HDPE pipe specified by AASHTO Section 17 are shown in Table 1. The short term tensile strength and modulus of elasticity are taken from the material specification ASTM D3350 based on a cell class of 435400C. For the 50-year properties, AASHTO Section 17 states that “these values are derived from hydrostatic design bases (HDB) and indicate a minimum 50-year life expectancy under continuous application of tensile stress”. For the75-year and 100-year modulus, values were proposed in NCHRP Report 631 based on the relaxation modulus . However, the long-term tensile strength of HDPE was not presented in the NCHRP Report 631.

Table 1 – Mechanical Properties for Design HDPE Pipes (NCHRP 631)

Material	Tensile Values (psi)				Modulus Values (psi)			
	Short-Term	Long-term			Short-term	Long-term		
		50-yr	75-yr	100-yr		50-yr	75-yr	100-yr
Corrugated Pipe	3000	900	NA	NA	110,000	22,000	21,000	20,000
Profile Pipe	2600	NA	NA	NA	80,000	20,000	19,000	18,000

Note: NA = not available

In this report, the test methods used to evaluate the 100-year tensile strength and modulus of corrugated HDPE pipe are described, and the procedures to determine the specified values are presented.

2. LONG-TERM TENSILE STRENGTH

As stated previously, the 50-year tensile strength of 900 psi was obtained using the HDB test method (ASTM D2837) by linearly extrapolating the creep rupture test data to 50 years. However, this methodology can only be implemented if the ductile-to-brittle transition point occurs beyond 100 years at the temperature of 23^{o}C. In order to select the appropriate test method to evaluate the long-term tensile strength, the ductile-to-brittle transition point of corrugated HDPE pipes should first be determined.

The stress crack resistance test (FM 5-572, Procedure B) was performed on junction specimens taken from a 24-in diameter corrugated pipe (Sample P-A). The test conditions used to establish the transition point are shown in Table 2, and the test data are presented in Figure 1 by plotting applied stress versus failure time in a log-log scale. The transition points, which correspond to the onset of the brittle curve, are also included in Table 2.

Table 2 – Test conditions for stress crack resistance test using pipe junction specimens

Pipe Sample	Applied Stress (psi)	Test Temperature (°C)	Transition Stress (psi)	Transition Time (hour)
P-A	950, 850, 750, 650	80	850	79.7
	1000, 900, 800	70	900	472.3

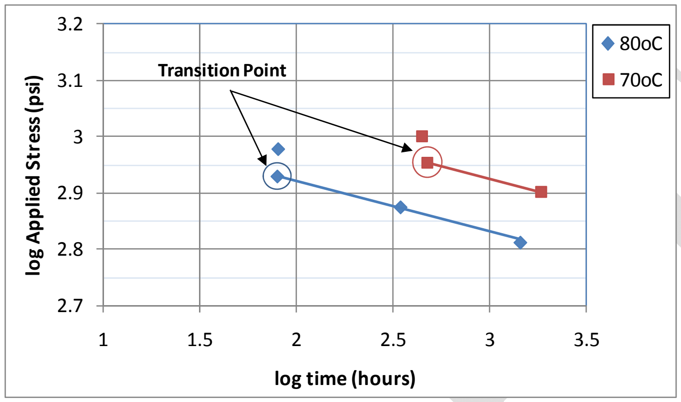


Figure 1 – Stress crack resistance test data of Sample P-A

The ductile-to-brittle transition point at 23°C can then be predicted from the transition value of 70°C or 80°C using Popelar's shift factors, as expressed in Eq. (1) and (2) (Popelar et al. 1991). Table 3 shows the two predicted transition points at 23°C; the transition stress falls between 1650 and 1550 psi and the transition time ranges from 5 to 9 years. Clearly, the long-term tensile strength should not be determined from the ductile portion of the creep rupture curve. Instead, it should be obtained from the brittle portion of the curve. However, it should be emphasized that the predicted failure time of the SCR-junction test for Sample P-A at 23°C under the applied stress of 500 psi is well over 100 years, as shown in Figure 2.

$$a_T = exp[-0.109(T - T_R)] \quad (1)$$

$$b_T = exp[0.0116(T - T_R)] \quad (2)$$

where: a_T = horizontal shift function (time function), b_T = vertical shift function (stress function)
T = temperature of the test, in K, T_R = target temperature, in K

Table 3 – Predicted Transition Stress and Transition Time at 23°C

Based on test data at temperature of	Transition Stress (psi)	Transition Time (years)
80°C	1647	4.5
70°C	1552	9.0

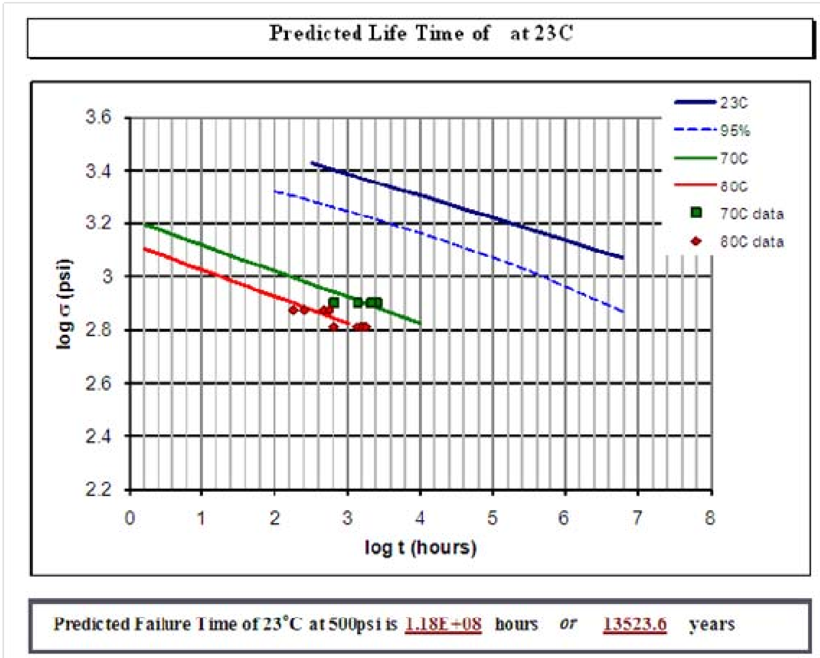


Figure 2 – Predicted stress crack failure time under 500 psi at 23°C

3.1. Determine the 100-year Tensile Strength

The 100-year tensile strength shall be determined using the SCR test. The outline of the test procedure is presented, as follows:

a) Establish the SCR curve using FM 5-572, Procedure B.
b) Perform tests at temperatures of 70 and 80°C and applied stresses of 650 and 450 psi.
c) Extrapolate the test data to generate the SCR curve at 23°C with 95% confidence.
d) Determine the applied stress corresponding to 100 years from the predicted 23°C curve.

Figures 3 and 4 show the test results and predicted 23°C brittle curve of two SCR junction tests. Curves shown in Figure 3 were obtained from pipe that was **not** certified for the 100-year interim specification. In this case, the predicted tensile stress that would induce stress cracking after 100 years is 550 psi. Contrary, curves shown in Figure 4 were generated from junction specimens taken from Sample P-A pipe, which is a 100-year certified pipe. The predicted 100-year tensile strength is 930 psi.

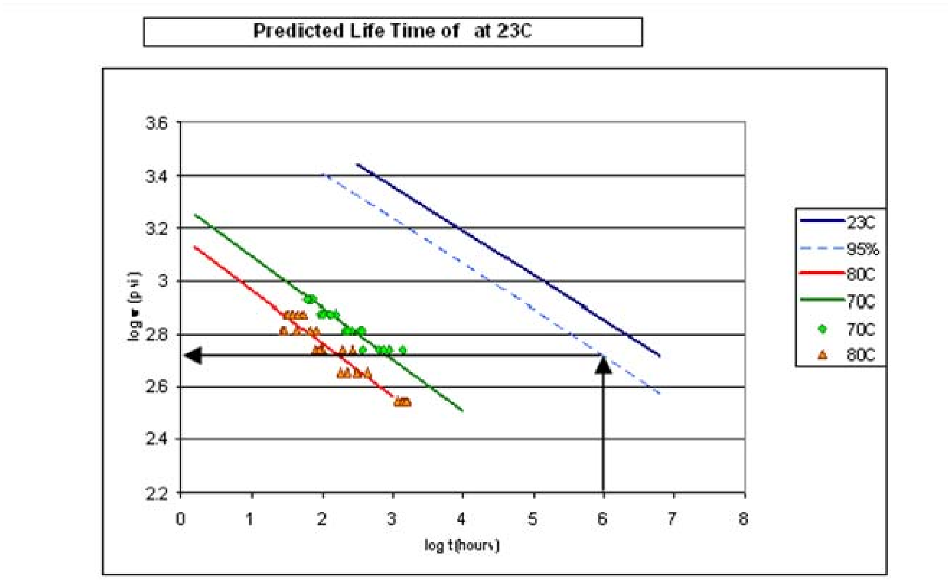


Figure 3 – Determine 100-year tensile stress using predicted 23°C SCR curve from a pipe not being certified for 100-year interim specification

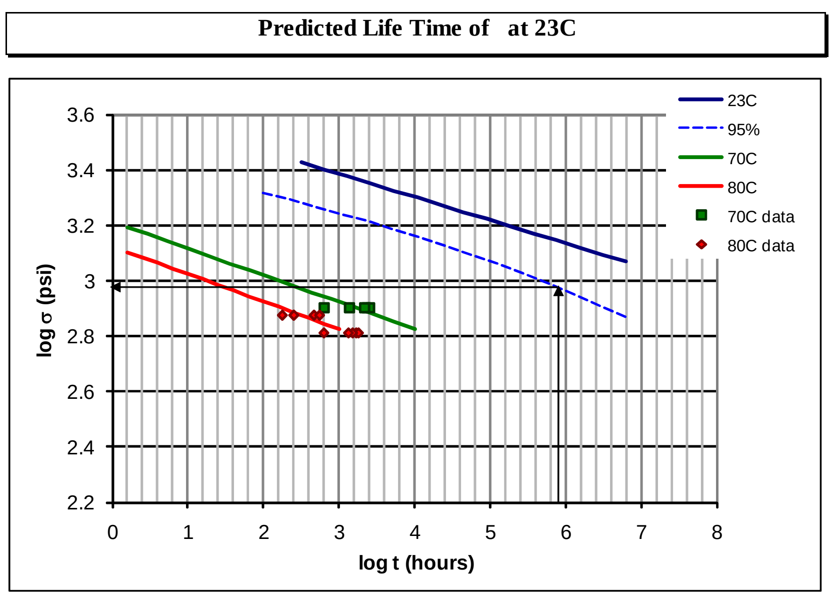


Figure 4 – Determine 100-year tensile stress using predicted 23°C SCR curve from the P-A pipe which has approved for 100-year interim specification.

To be conservative, the 100-year specified values for SCR-junction test (80°C failure times of 100 hr at 650 psi and 430 hr at 450 psi; at 70°C, failure time is 500 hr at 650 psi) are used to dertermined 100-year tensile strength with 95% confidence. The predicted value is approximately 800 psi, as depicted in Figure 5.

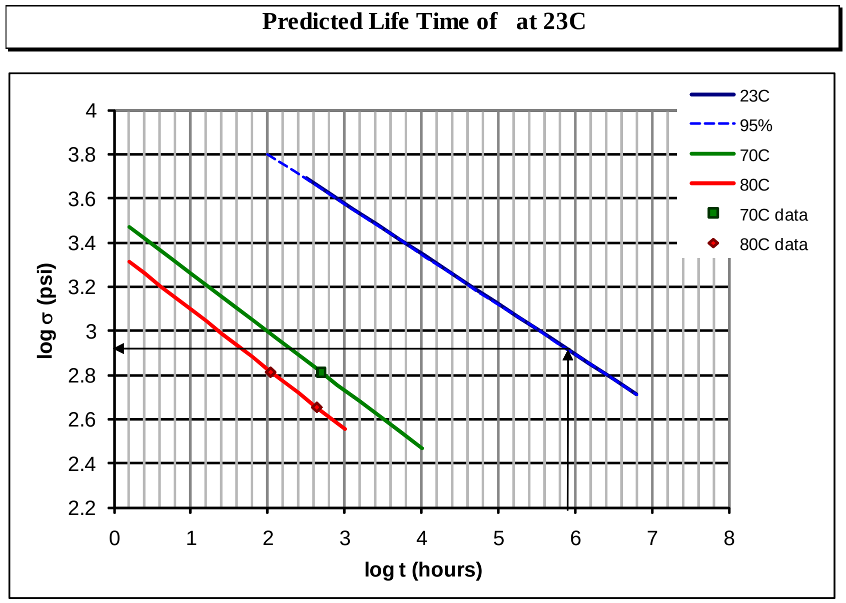


Figure 5 – Determine 100-year tensile strength using predicted 23°C SCR curve obtained from minimum requirements of the 100-year interim specification.

3.2 100-year Tensile Strength Recommendation

- The 100-year tensile strength shall be determined by the stress crack resistance junction test based on FM 5-572, procedure B.
- A conservative estimate of the 100-year tensile strength may be established by using parameters defined in Section 948 specification for the SCR requirement (i.e. terminating the junction test at 110 hours for the 176 deg. F / 650 psi condition, 430 hours for the 176 deg. F / 450 psi condition, and 500 hours for the 158 deg. F / 650 psi condition). Based on these test parameters, the 100-year tensile strength for corrugated HDPE pipe is predicted to be 800 psi.
- To establish a higher estimate for the 100-year tensile strength, With FDOT oversight Industry may perform the stress crack resistance junction test based on FM 5-572, procedure B. All tests must be carried out to failure so that the new 100 year tensile strength can be determined.
- The two test methods, FM 5-575 and FM 5-576, are no longer relevant to the determination of 100-year tensile strength, and they shall be removed from the specification.

3. LONG-TERM MODULUS

For the evaluation of long-term creep modulus of corrugated HDPE pipe, the Stepped Isothermal Method (SIM) test procedure (ASTM D 6992) has been incorporated into the new Florida DOT test method (FM 5-577). SIM is a relatively new method; it was developed in late 1990 to assess creep behavior of geosynthetics, particularly geogrid (Thornton et al., 1998(a) and (b); Greenwood and Voskamp, 2000). A similar methodology was first used by Sherby and Dorn (1958) to evaluate the creep property of polymethyl-methacrylate (PMMA). The method combines both time-temperature-superposition (TTS) and Boltzmann superposition. In SIM, a single specimen is exposed to a sequence of temperature steps while is subjecting to a constant applied load. A series of individual creep curves is generated from which a master creep curve is formed by shifting the individual creep curves horizontally and vertically. The advantage of SIM is further shortening the testing time and avoiding material variability in comparison to TTS.

Before finalizing the standard test method, FM 5-577, a series of round robin programs were organized. The first round robin (RR) program (RR #1) took place in January 2011 with four participate labs and the fourth and final RR program was concluded in November 2011.

3.1. RR #1 Program

The purpose of the RR #1 program was to identify the discrepancy of the test procedure and apparatus among the four participating labs, particularly the method to measure the creep strain (cross-head movement of the tensile machine vs. strain gauge). Prior starting the RR program, decisions were made regarding the test specimen shape and the gauge length. Two types of test specimen, dumbbell and strip specimen, were included in the program dependent on the method used to measure the creep strain, as shown in Table 4. In order to have a relatively uniform thickness within the gauge length region, test specimens were taken from the liner portion of the pipe, as depicted in Figure 6.

Table 4. The test parameters of SIM implemented in RR#1

Strain Measurement Method	Strain Gauge	Cross-head Movement
Test Specimen	ASTM D 638, Type IV (Dumbbell specimen)	ASTM D 882 (1-inch strip specimen)
Gauge Length	1-inch	2-inch
Grip Distance	2.5-inch	2-inch

Form the result of RR#1 program, two important findings were identified:

- Strain gauge must be used to measure the creep strain. Figure 7 shows that the measured creep strain is higher using the crosshead of the machine than strain gauge for 1-in strip test specimen.

- The duration to reach equilibrium at each temperature step is critical in achieving a smooth transition between two adjacent strain segments, as illustrated in Figure 8. It is recommended that the duration to reach equilibrium at each temperature step should be within 15 minutes.

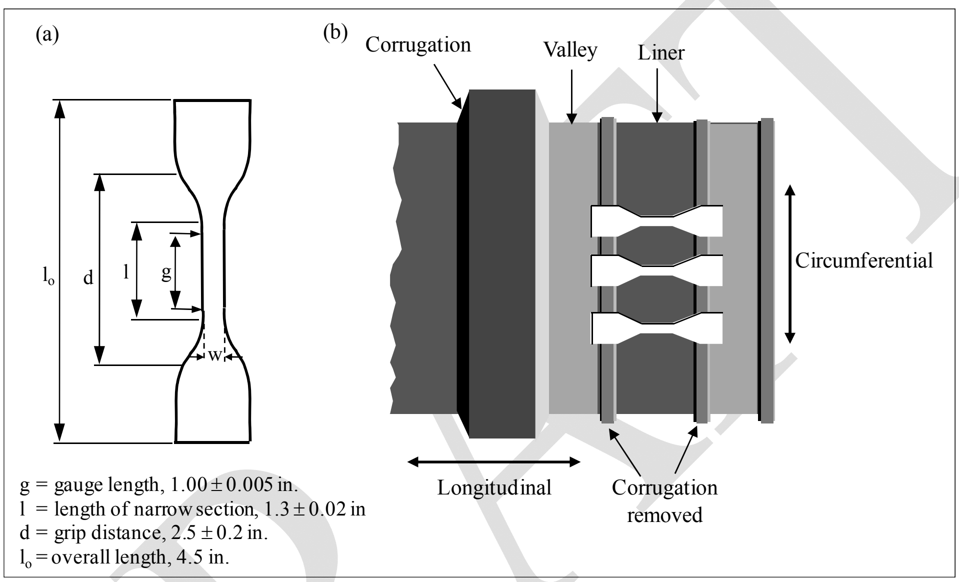


Figure 6 – ASTM D 638 type IV specimen used for the SIM test to measure creep modulus

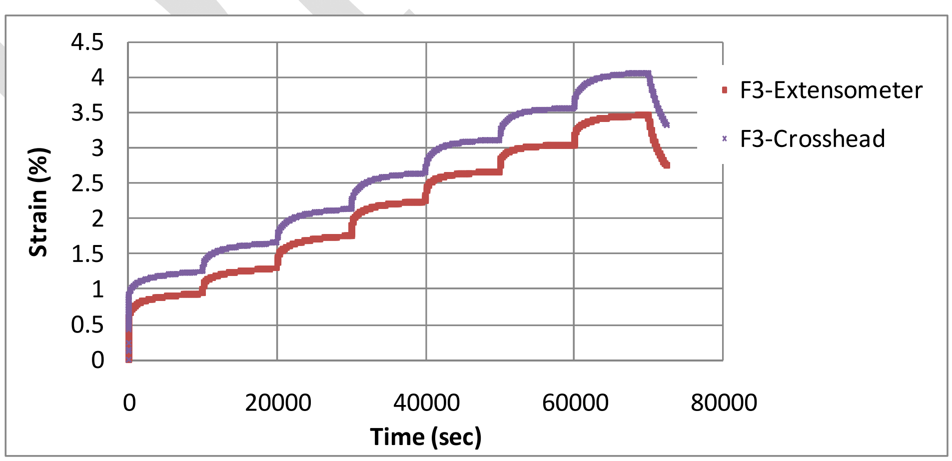
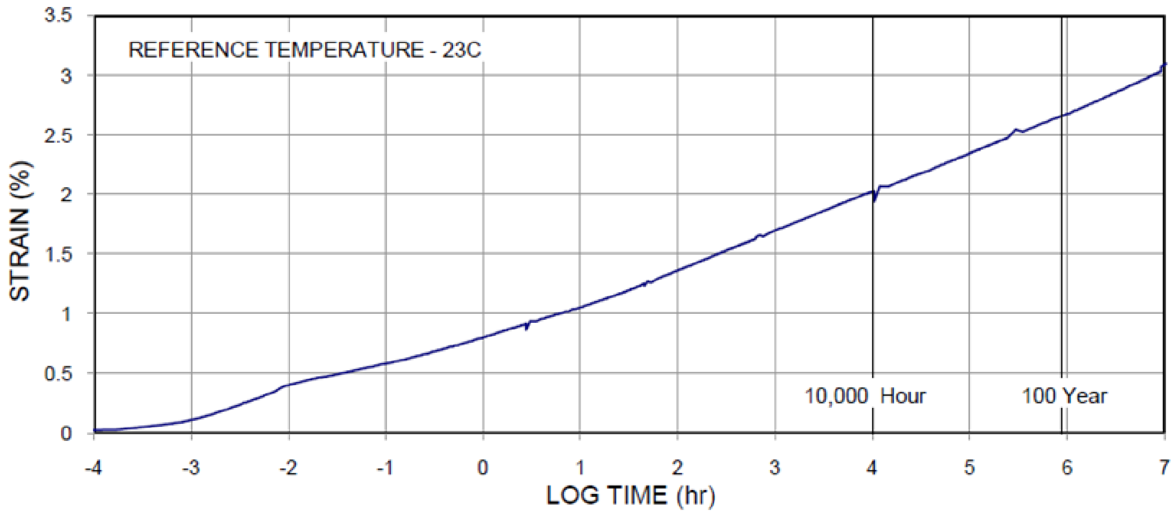
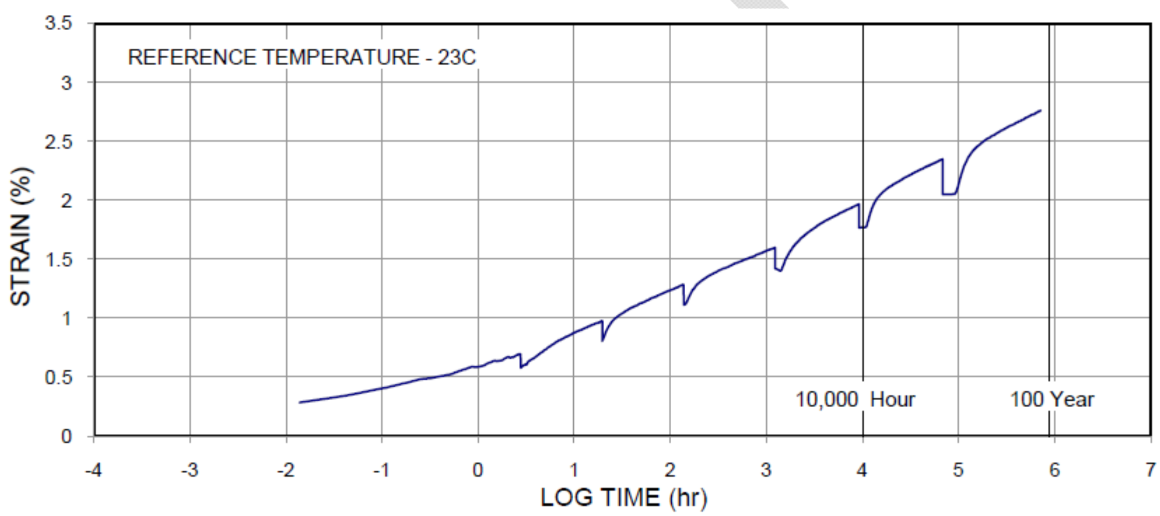


Figure 7. Comparing creep strain measurement between extensometer and crosshead



(a) Short equilibrium temperature time yielding smooth joining between adjacent strain segments



(b) Long equilibrium temperature time yielding poor joining between adjacent strain segments

Figure 8. Effect of time interval to reach equilibrium at each temperature step

3.2. RR #2 Program

Based on the findings of RR#1, the RR#2 program was organized to investigate the variability of temperature control and strain gauge. Furthermore, test specimens were taken from the "top-hat" at the pipe end instead of the liner portion of the pipe. The benefit of using the top-hat material is because of its uniform thickness. Also a longer test specimen, ASTM D 638 Type I, was used in comparison to ASTM D 638 type IV. The gauge length of Type I specimen is 2-in while it is 1-in for the Type IV specimen, making it easier to attach the strain gauge. Figure 9 shows the configuration of the Type I dumbbell specimen.

Figure 10 shows the SIM curves obtained from four participating labs. The creep strain obtained from Lab-1 is much higher than the others. This lab was the only lab using an Instron machine to perform the SIM test. The other three labs used dead-load for their SIM tests. It is believed that the test specimen experienced additional deformation to compensate the compressive load induced by the thermal expansion of the metal rods and grips.

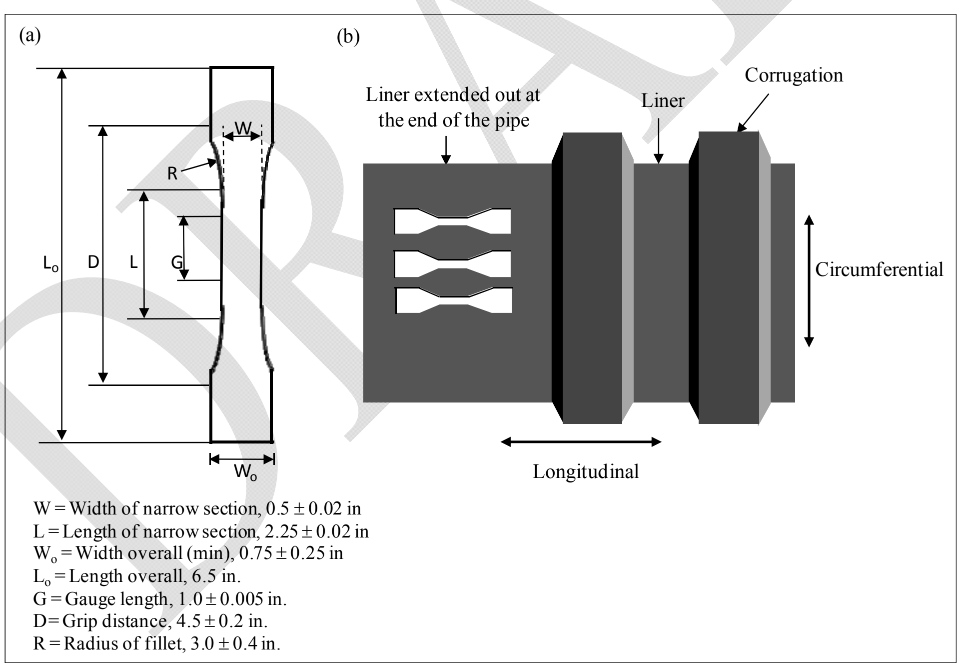


Figure 9. ASTM D 638 type I specimen used for the SIM test to measure creep modulus

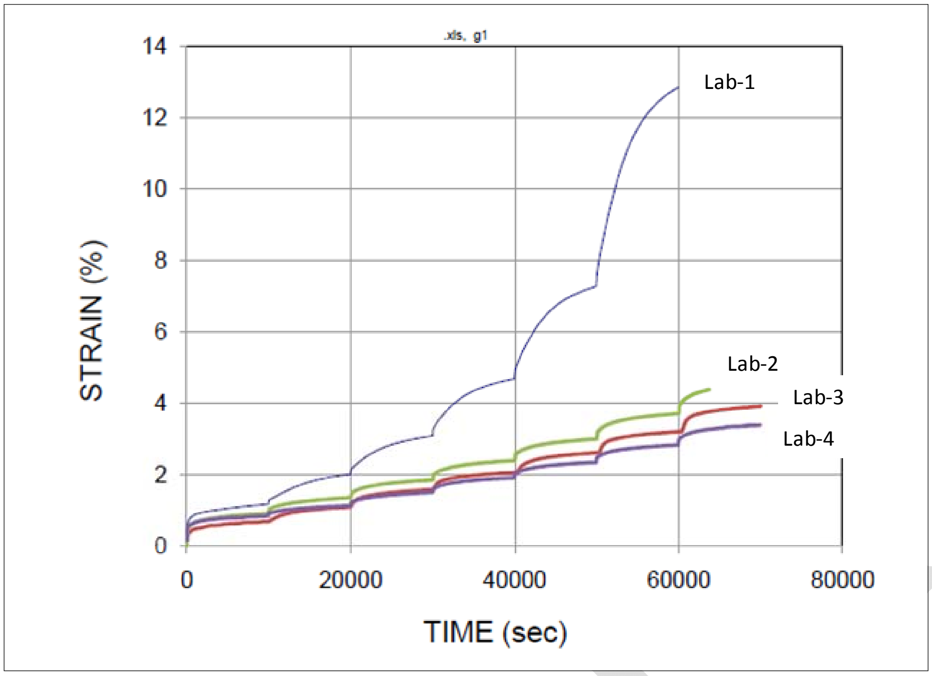


Figure 10. Comparing SIM strain test data obtained from four labs

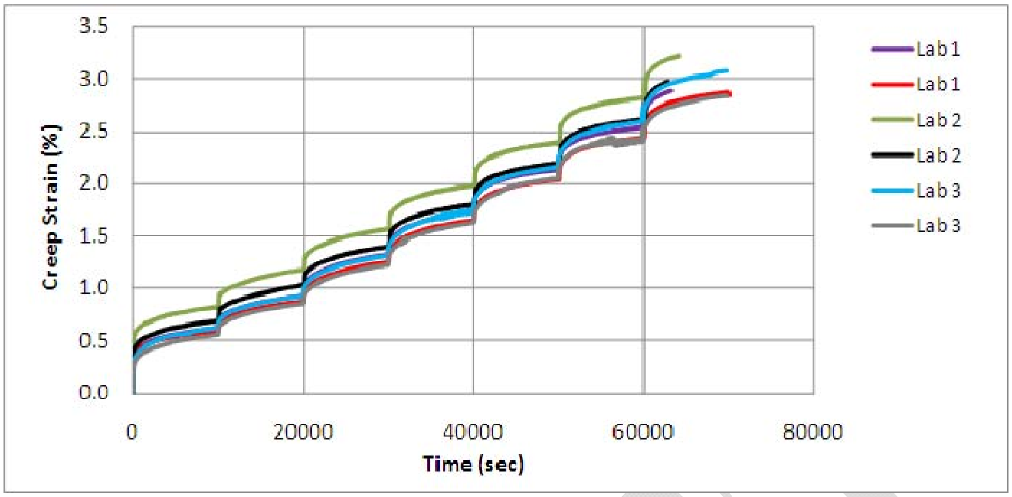
Form the results of RR#2 program, two important findings were identified:

- The top-hat material is too thin to be used for the SIM test. The thickness of this portion of the liner was found to be much thinner than the pipe liner (~ 0.045-in versus ~ 0.07-in). A stress concentration may be introduced by the strain gauge to such thin material subsequently affecting the creep strain.

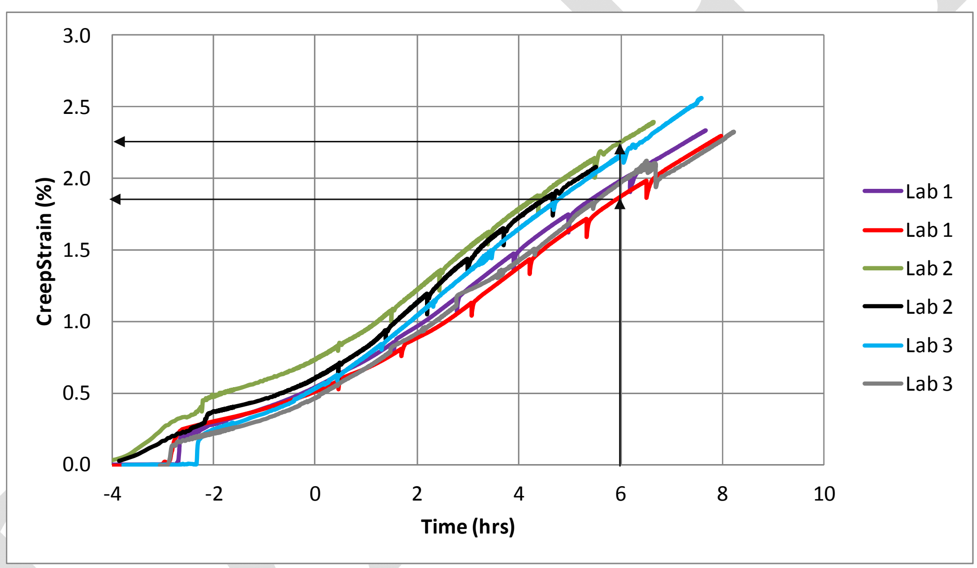
- Dead-weight shall be used for applying force to the test specimen in the SIM test.

3.3. RR #3 Program

The purpose of the RR#3 program is to isolate the variability contributed by the test equipments from that by the test specimens. The dumbbell shaped specimen, ASTM D 638, Type IV, was used in this program. The test specimens were taken from the compressive molded plaques instead of the pipe liner to minimize material variability. Figure 11 shows six sets of SIM test data from three participating labs. The 100-year creep strain values range from 1.85% to 2.25% corresponding to creep modulus of 22,000 to 27,000 psi.



(a) SIM test result



(b) Master curves obtained from SIM data

Figure 11. SIM test data from three participating labs of RR#3 program.

From the results of first three round robin programs, the appropriate test conditions and specimen's dimensions for the SIM test have been identified.

- The test specimen should be taken from the liner portion of the pipe using ASTM D638 Type IV die (recorded Figure 6).

- The starting temperature should be at 23°C, and then incrementally increases to 65°C at an interval of 7°C.
- The dwell time for each temperature step should be 10,000 sec.
- The FM 5-577 method was revised accordingly, and is included as Appendix of this report.

3.4. RR #4 Program

The purpose of RR#4 was to assess the effects of HDPE resin and pipe manufacturing process on the long-term modulus. The revised FM 5-577 test procedure was implemented in this RR program. Two replicates were performed for each sample. Table 4 shows the pipe samples evaluated in this program. All five pipe samples were taken from the 100-year certified pipes. All RR#4 SIM test data were analyzed using the computer program developed by TRI, Inc. to generate the creep master curve. Figure 12 shows an example of the SIM master curve from which the 100-year creep modulus was determine.

Table 4 – Test samples of RR #4 program

Code	Pipe Manufacturer	Pipe Diameter (in)	HDPE Resin
Sample A	1	24	I
Sample B	1	48	I
Sample C	1	24	II
Sample D	1	48	II
Sample E	2	24	III

Table 5 shows the 100-year creep modulus of five samples from the four participating labs. The Lab. 4 has the lowest value for all five samples. The Student's t-test method was used to determine the 95% confidence interval for each pipe sample and the result is shown in Table 6. The 100-year modulus values can be divided into two groups: Samples A, B, and E have an average modulus value around 22,500 psi, and Samples C and D have an average value of 20,700 psi. As shown in Table 4, Samples A and B were made from Resin I, while Sample C and D were made from Resin II. On the other hand, Samples A and C were taken from 24-in pipes produced from the vertical-opening mold, whereas Samples B and D were taken from 48-in pipes produced from the horizontal-opening mold. The result suggests that the long-term modulus value varies with the resin type more than the pipe processing. However, Resin I and Resin III were supplied by two chemical companies, and their properties were not investigated in this study.

Based on the data shown in Table 6, the 100-year long-term creep modulus of corrugated HDPE pipe is recommended to be 20,000 psi with 95% confidence.

Table 5 – 100-year modulus obtained from SIM

Sample	100 year Creep Modulus (psi)											
	Lab. 1			Lab. 2			Lab. 3			Lab. 4		
	Value	Ave.	Std Dev	Value	Ave.	Std Dev	Value	Ave.	Std Dev	Value	Ave.	Std Dev
A	27292 26915	27104	267	22010 26259	24135	3004	23198 22859	23029	240	21451 22244	21848	561
B	27061 25633	26347	1010	28564 23491	26028	3587	27362 26287	26825	760	19421	19421	na
C	24844 25086	24965	171	21222 22103	21663	623	26420 23158	24789	2307	18911 20082	19497	828
D	25150 24564	24857	414	21984 24117	23051	1508	26345 27137	26741	560	16140 20765	18453	3270
E	29701 30195	29948	349	25092	25092	na	25129 26444	25787	930	19785 22198	20992	1706

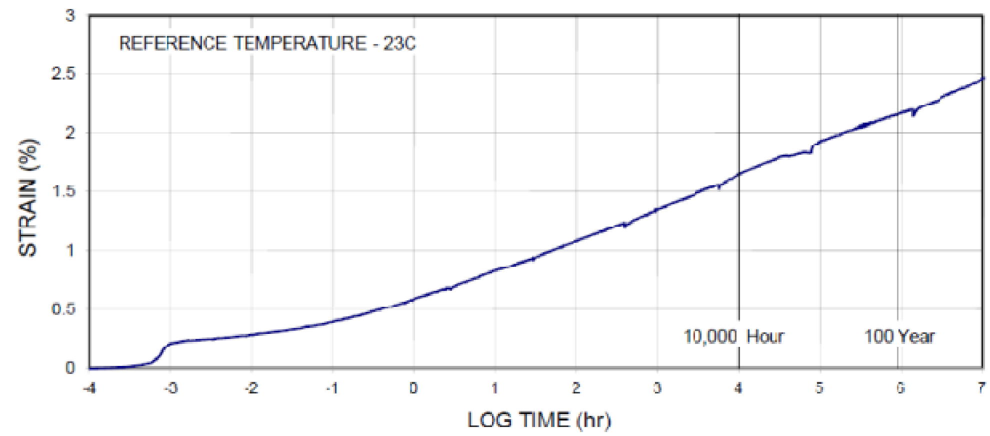
Table 6 – Using t-test to determined 95% confidence interval of 100-year creep modulus

Sample	A	B	C	D	E
100-year Creep Modulus (psi)	22010	28564	21222	21984	29701
	26259	23491	22103	24117	30195
	27292	27061	24844	25150	19785
	26915	25633	25086	24564	22198
	21451	27362	18911	16140	25129
	22244	26287	20082	20765	26444
	23198	19421	26420	26345	25092
	22859		23158	27137	
Ave.	24029	25403	22728	23275	25506
Std Dev	2388	3078	2621	3568	3752
Data point	8	7	8	8	7
Average	24029	25403	22728	23275	25506
Std Dev	2388	3078	2621	3568	3752
n	7	6	7	7	6
A	1.895	1.943	1.895	1.895	1.943
95%	**22319**	**22961**	**20851**	**20720**	**22530**

	Average Creep Stress:	500.1	psi			%UTS:	#DIV/0!
	Tensile Yield Strength:	0.0	psi			Rupture:	NO

Dwell Seq	t'	t	$(t-t')_i$	Vshift(%)	$\log A_T$	Temp	$\log A_T/T$
1	0	0.5	0.5	-	-	22.94	-
2	9000	10022	1022	-0.08	0.9901	30.09	0.1386
3	19200	20012	812	-0.09	1.1310	37.29	0.1571
4	29250	30002	752	-0.11	1.1561	44.54	0.1593
5	39200	39992	792	-0.11	1.1313	51.73	0.1575
6	49400	49982	582	-0.05	1.2669	58.75	0.1804
7	59650	59971	321	-0.12	1.5159	65.80	0.2151
8							
9							
10							
						AVG	0.1678

Creep modulus (psi) @ 23C		% strain @ 23C	
10,000 hour	100 year	10,000 hour	100 year



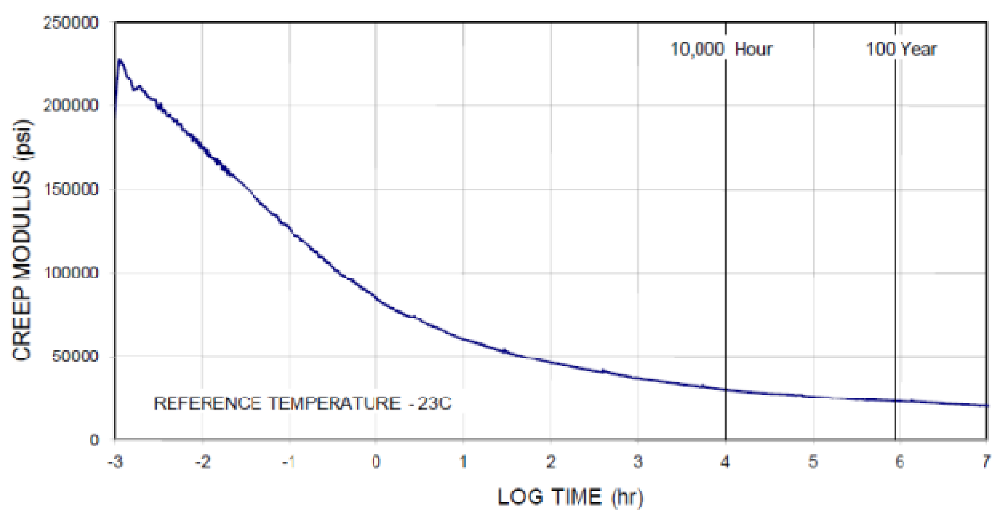


Figure 12. An example of SIM master curve analyzed by program developed by TRI, Inc.

5. SPECIFICATION

The TABLE 1 in Section 948 is modified by including the long-term tensile and modulus, as shown below:

Table 1			
Stress Crack Resistance of Pipes			
Pipe Location	Test Method	Test Conditions	Requirement
Pipe Liner	FM 5-572, Procedure A	10% Igepal® solution at 122°F and 600 psi applied stress, 5 replicates	Average failure time of 5 specimens shall be ≥18.0 hours, no single value shall be less than 13.0 hours.
Pipe Corrugation[1], (molded plaque)	ASTM F-2136	10% Igepal® solution at 122°F and 600 psi applied stress, 5 replicates	Average failure time of 5 specimens shall be ≥24.0 hours, no single value shall be less than 17.0 hours.
Junction	FM 5-572, Procedure B and FM 5-573	Full Test[2,3]: Test at 3 temperature/stress combinations: 176°F at 650 psi 176°F at 450 psi 158°F at 650 psi; 5 replicates at each test condition	Determine failure time at 500 psi at 73.4°F ≥ 100 years (95% lower confidence) using 15 failure time values[4]. The tests for each condition can be terminated at duration equal to or greater than the following criteria: 110.0 hr at 176°F 650psi 430.0 hr at 176°F 450 psi 500.0 hr at 158°F 650 psi
		Single Test[5]: Test temperature 176°F and applied stress of 650 psi.; 5 replicates	All 5failure time values must be equal to or greater than 110.0 hr

Table 1			
Longitudinal Profiles[6]	FM 5-572, Procedure C, and FM 5-573	Full Test[2,3]: Test at 3 temperature/stress combinations: 176°F at 650 psi 176°F at 450 psi 158°F at 650 psi; 5 replicates at each test condition	Determine failure time at 500 psi at 73.4°F ≥ 100 years (95% lower confidence) using 15 failure time values[4]. The tests for each condition can be terminated at duration equal to or greater than the following criteria: 110.0 hr at 176°F 650psi 430.0 hr at 176°F 450 psi 500.0 hr at 158°F 650 psi
		Single Test[5]: Test temperature 176°F and applied stress of 650 psi.; 5 replicates	All 5 failure time values must be equal to or greater than 110.0 hr
Oxidation Resistance of Pipes			
Pipe Location	Test Method	Test Conditions	Requirement
Liner and/or Crown[7]	OIT Test (ASTM D-3895)	2 replicates (to determine initial OIT value) on the as manufactured (not incubated) pipe.	The individual OIT test value must equal to or greater than 25.0 minutes
Liner and/or Crown[7]	Incubation test FM 5-574 and OIT test (ASTM D-3895)	Three samples for incubation of 265 days at 176°F[8] and applied stress of 250 psi. One OIT test per each incubated sample	Average OIT value must be ≥3.0 minutes[9] (no value shall be less than 2.0 minutes)
Liner and/or Crown[7]	MI test (ASTM D-1238 at 190°C/2.16 Kg)	2 replicates on the as manufactured (not incubated) pipe.	< 0.4 g/10 minutes
Liner and/or Crown[7]	Incubation test FM 5-574 and MI test (ASTM D-1238 at 190°C/2.16 Kg)	2 replicates on the three aged sampled after incubation of 265 days at 176°F[8] and applied stress of 250 psi	MI Retained Value[9, 10] shall be greater than 80% and less than 120%.
Long Term Tensile Properties			

Table 1			
Pipe Location	Test Method	Test Conditions	Requirement
Liner	FM 5-577	2 replicates at applied stress of 500 psi	Determine creep modulus at 100-year at 73.4°F ≥ 20,000 psi (95% lower confidence)
Junction[11]	FM 5-572, Procedure B	Test at 3 temperature/stress combinations: 176°F at 650 psi 176°F at 450 psi 158°F at 650 psi; 5 replicates at each test condition	Determine tensile strength at 100-year at 73.4°F ≥ 800 psi (95% lower confidence) using 15 failure time values[4,11]. The tests for each condition can be terminated at duration equal to or greater than the following criteria[12]: 110.0 hr at 176°F 650psi 430.0 hr at 176°F 450 psi 500.0 hr at 158°F 650 psi

Note: FM = Florida Method of Test.

[1] Required only when the resin used in the corrugation is different than that of the liner.

[2] A higher test temperature (194° F) may be used if supporting test data acceptable to the State Materials Engineer is submitted and approved in writing.

[3] Full test shall be performed on alternative pipe diameter of pipe based on wall profile design, raw material cell classification, and manufacturing process. Full test must be performed on maximum and minimum pipe diameters within a manufacturing process.

[4] Computer program to predict the 100 year SCR with 95% lower confidence can be obtained from FDOT.

[5] Single test for the junction and longitudinal profile may be used on alternating pipe sizes within a manufacturing process. Single point tests may not be used on maximum and minimum pipe sizes within a manufacturing process except by approval of the Engineer. Single point tests may be used for quality assurance testing purposes.

[6] Longitudinal profiles include vent holes and molded lines.

[7] OIT and MI tests on the crown are required when resin used in the corrugation is different than that of the liner.

[8] The incubation temperature and duration can also be 187 days at 185°F.

[9] The tests for incubated and "as-manufactured" pipe samples shall be performed by the same lab, same operator, the same testing device, and in the same day.

[10] The MI retained value is determined using the average MI value of incubated sample divided by the average MI value of as-manufactured pipe sample.

[11]The junction test results from the SCR test may be used to establish the minimum 100-year tensile strength of 800 psi

6. REFERENCES

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Appendix – FM 5-577

Florida Method of Test for
Predicting Long-Term Modulus of Corrugated HDPE Pipes

Designation, FM 5-577 (February 6, 2012)

1. SCOPE

1.1. This test method is used to predict the long-term modulus of high density polyethylene corrugated pipes in view of the Florida DOT 100-year design service life requirement.

1.2. The test utilizes the Stepped Isothermal Method (SIM), ASTM D 6992, to evaluate the creep modulus of corrugated HDPE pipe at 100 years.

1.3. The test utilizes dumbbell shaped specimen taken from the finished pipe across the liner section along the longitudinal direction of the pipe.

1.4. The tests shall be performed at minimum of seven temperature steps.

1.5. The creep data obtained from the elevated temperatures are shifted to a site specific temperature, 73.4°F (23°C), using the procedure described in ASTM D 6992.

2. REFERENCED DOCUMENTS

2.1 Standard Methods:

ASTM D638	Tensile Properties of Plastics
ASTM D5947	Physical Dimensions of Solid Plastics Specimens
ASTM D6992	Accelerated Tensile Creep and Creep Rupture of Geosynthetic Materials Based on Time-Temperature Superposition Using the Stepped Isothermal Method (SIM).
FM 5-572	Florida Method of Test for Determining Stress Crack Resistance of HDPE Corrugated Pipes

3. APPARATUS

3.2 Blanking Die – A die suitable for cutting test specimens to the dimensions and tolerances specified in ASTM D 638 Type IV, see Figure 1 (a).

3.3 Caliper capable of measuring to +/- 0.0005 in (+/- 0.0127 mm).

3.4 Grips – Grips for SIM shall have a serrated face at least 1 inch (25.4 mm) wide, similar to the grips used for tensile tests. Neither slippage nor excessive stress causing premature rupture shall be allowed to occur.

3.5 Creep Testing Equipment – A universal testing machine or a dead-weight loading system with the capability of measuring the applied load and monitoring strain with time.

3.6 Strain Gauge – In order to measure the distance between two designated points within the gage length of the test specimen as the specimen is stretched, the strain gauge (extensometer) shall be used. It shall be essentially free of inertia at the specified speed of testing.

3.7 Environmental temperature chamber – The chamber shall be capable of maintaining specimen temperature ± 1.8°F (1.0°C) in range from 68 to 212°F (20°C to 100°C). To achieve test temperatures below the laboratory ambient temperature, a cooling device shall be used.

3.8 Data acquisition system – Suitable for collecting strain values at the desire time interval.

3.9 Bench Grinder – If necessary.

4 SAMPLING

4.1 Identify the manufacturing direction of the pipe.

4.2 Removing five 5-inch (127-mm) long sections from a single stick of pipe in a helical pattern similar to FM 5-572.

4.3 Use a band saw to remove the two corrugations from the 5-inch (127 mm) section. The height of the remaining corrugation on each side of the valley shall be minimum of 0.25-inch (6.4 mm) and maximum of 0.5-inch (12.7 mm). The manufacturing direction must be clearly marked on each of the five sections.

5 TEST SPECIMEN

5.1 The corrugation side must be placed so that it is facing the die.

5.2 The specimen shall be die cut from the liner section of the pipe. The liner shall be positioned within the center of the specimen as shown in Figure 1(b).

Note 1: The specimen shall be removed carefully from the die to avoid imposing stress at the specimen.

Note 2: If necessary, remove the corrugation section on the specimen by grinding to ensure a flat surface at the gripping surface. The residual thickness must be equal or thicker than that of the gauge length region.

5.3 Measure the thickness of the liner section of the specimen using a caliper. Three measurements shall be recorded and the lowest value shall be used in the applied load calculation.

5.4 Measure the width of the specimen using a caliper at the lowest thickness location. The tips of the caliper shall be positioned at the midpoint of the thickness of the specimen.

5.5 A single specimen is used in the test.

6 TEST TEMPERATURE

6.1 Minimum of seven temperature steps shall be used for SIM.

6.2 The temperature steps are 73.4 to 149°F (23 to 65°C) at 12.6°F (7°C) increments.

6.3 The ramping time for the test specimen to achieve the target temperature in the environmental chamber shall be within 15 minutes.

7 PROCEDURES

7.1 The grip distance of the test is 2.5-inch (64.5 mm).

7.2 The specimen shall be positioned so that the pipe liner is at the center of the grip distance.

7.3 Secure the test specimen between upper and lower grips.

7.4 Attach the strain gauge on the 1.3-inch (34.3 mm) section of the test specimen. The gauge length shall be 1-inch (25.4 mm).

7.5 The environmental chamber temperature shall be set at the starting test temperature of 73.4±1.8°F (23±1°C). The test specimen shall be held at the starting test temperature for 30 minutes.

7.6 Achieve the target test stress of 500±10 psi (3.4±0.07 MPa) by applying appropriate load to the specimen at a controlled rate.

7.7 Start the timer of the temperature controller. The dwell time for each temperature step shall be 10,000 seconds.

7.8 Data acquisition system shell record strain values at minimum rate of two readings per second during the initial loading ramp portions of tests and a minimum rate of two readings per minute during constant load portions of tests.

7.9 Terminate the test after seven temperature steps, 73.4, 86, 98.6, 111.2, 123.8, and 136.4, and 149°F (23, 30, 37, 44, 51, 58, and 65 °C).

8 DATA ANALYSIS

8.1 Plot creep strain versus linear time.

8.2 Plot creep strain versus log time after rescaling the temperature segments using following procedures and illustrated in Figure 2.

8.2.1 Except for the first temperature segment, the semi-logarithmic slopes of a strain curve at the beginning portion of a higher temperature dwell segment shall be adjusted to match the slope of the end portion of the preceding lower temperature dwell segment by subtracting a time “t” from each of the dwell times of higher temperature steps.

8.2.2 After rescaling as 8.2.1, re-plot creep strain by employing vertical shifts for each elevated temperature to account for system thermal expansion.

8.2.3 Employ horizontal shifts by moving evaluated temperature dwell segments to the right of the initial reference temperature dwell segment. The resulting creep strain versus log-time curves shall be a smooth curve.

8.3 Determine the strain value at 100-year and calculate 100-year modulus using Eq. (1).

$$E_{100-yr} = \frac{\sigma_{applied}}{\varepsilon_{100-yr}} \tag{1}$$

Where: E (psi) is modulus,
σ (psi) is stress (applied load/minimum cross sectional area), and
ε (%) is creep strain.

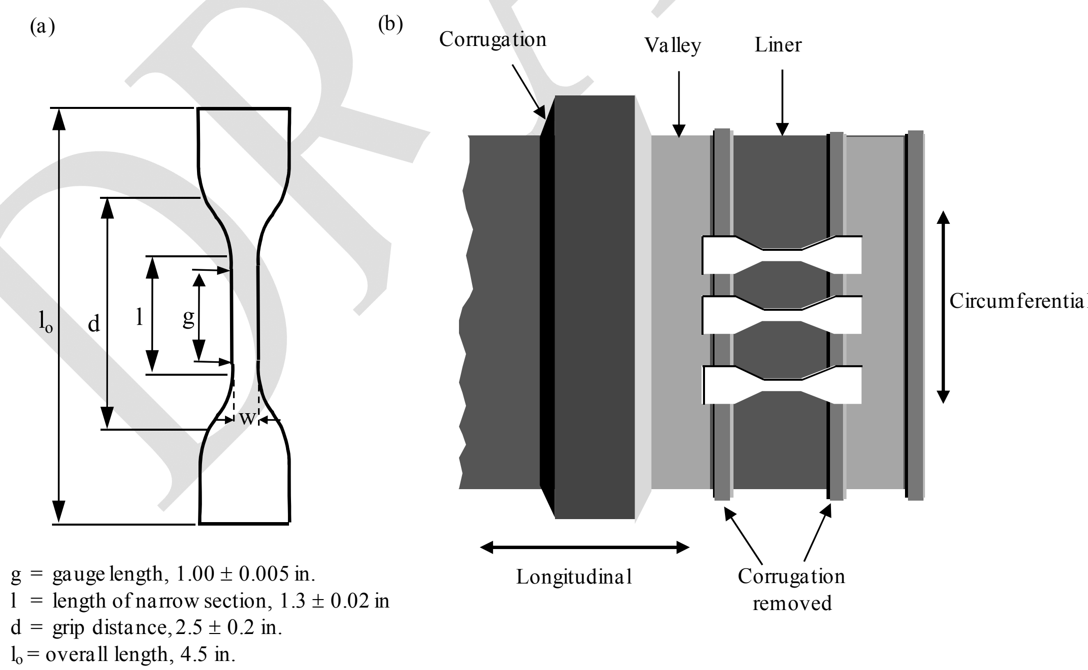

Figure 1 – (a) Test specimen dimensions and
(b) Location of the test specimen die cut from the corrugated HDPE pipe.

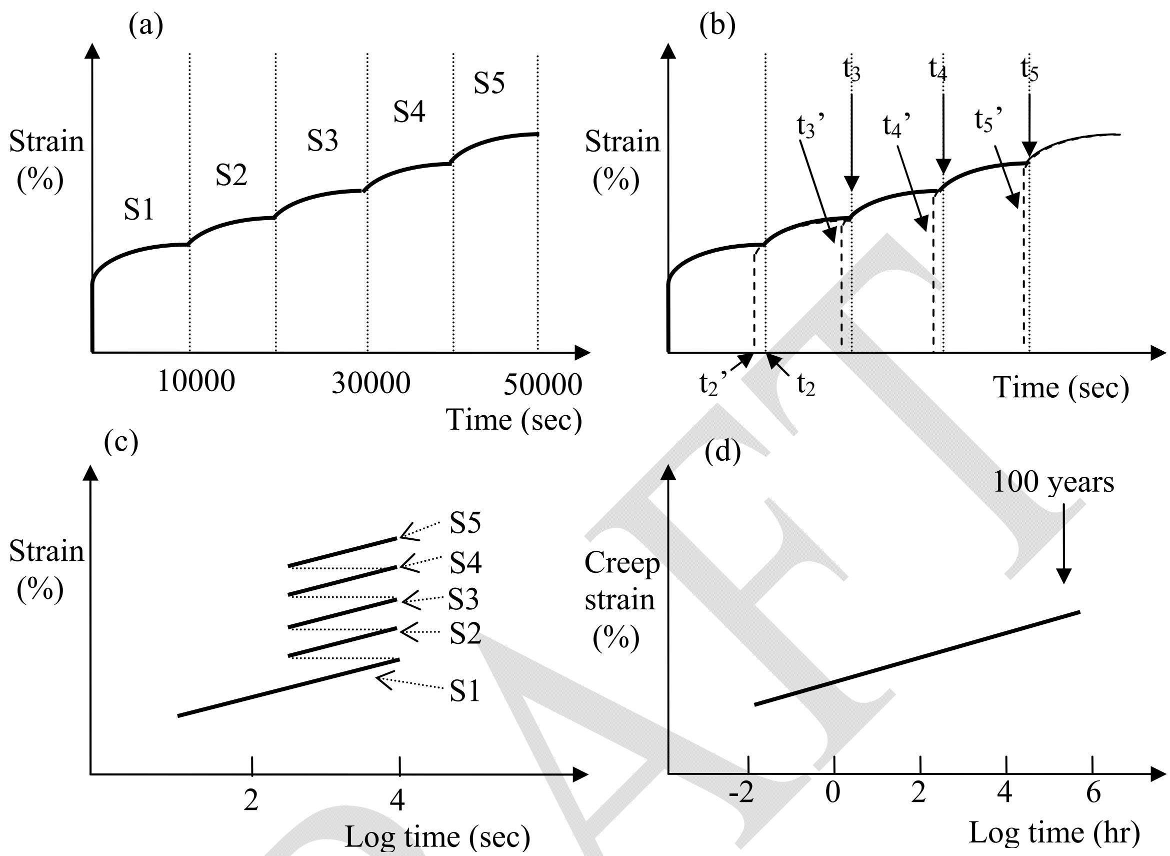

Figure 2 – Procedure to generate a tensile creep master curve from a SIM test